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NAVAL UNDERWATER SYSTEMS CENTER
NEW LONDON LABORATORY
NEW LONDON, CONNECTICUT 06320

Technical Memorandum

MICROBUBBLE SIZE DISTRIBUTIONS DATA COLLECTION AND ANALYSIS

Date: 14 January 1985

Prepared by: James J. Gallagher
JAMES J. GALLAGHER
Surface Ship Sonar Department

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14. ABSTRACT
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ADMINISTRATIVE INFORMATION

This memorandum was prepared under Job Order No. A62660, sub-project SF 43400391, "Air Emitting Strut Evaluation Program", Principal Investigator: J. J. Gallagher, Code 33A2. The work was performed in support of DTNSRDC Task Area SF 43400391, Program Element 62534N, "Air Emitting Strut Evaluation Program". The author is located at the Navy Underwater Systems Center, New London Laboratory, New London, Connecticut 06320.

INTRODUCTION

Properties of micron-sized bubble aggregates in sea water were investigated to determine their influence on the behavior of acoustic energy. Interest exists in optimizing the character of a bubble aggregate layer with respect to its influence on acoustic behavior. A towable strut was constructed to produce a layer of air bubbles at ship speeds of up to 10m/s (20 knots). The air-release holes in the strut were 1.2 mm (3/64") in diameter, and were uniformly distributed along the strut.

Bubble sizes and size distributions were influenced by ship speeds. Below speeds of about seven knots a non-uniform size distribution was evident as many large bubbles were present. Above that speed, and certainly above ten knots, bubble sizes were small and the size distribution much more uniform. Because of the turbulent nature of the flow behind the air generator strut the individual bubble distribution was highly non-uniform, with denser "clouds" of bubbles separated by more rarified zones. This investigation focussed on the bubble aggregates generated at ship speeds greater than 5 m/s (10 knots).

The critical physical characteristics of the bubble aggregate, as related to acoustic properties, that could reasonably be measured at sea, were deemed to be: percent air volume (or void ratio), bubble layer thickness, and bubble size and size distribution. The bio-chemical properties of bubble surfaces were not considered as a first-order problem during this study. This paper will discuss bubble size and size distribution measurements in sea water while underway. A technique to detect the presence of bubbles and layer thickness at high flow rates is described by Holmberg, et al.[1]

A literature search was conducted to identify candidate micro-bubble size measurement techniques. The search was narrowed by the limiting conditions of ship speeds greater than 5 m/s (10 knots), a turbulent medium, and vibration of the bubble generator strut-camera assembly. Because of these dynamic operating conditions techniques employing finely collimated beams, i.e. lasers, x-rays, ultrasonics, etc. were rated a low priority; scattering interference of high frequency active acoustic or optical signals from these aggregates was also considered troublesome.

Although a three-dimensional measurement of size distributions is ultimately desired photography of a plane was chosen as an interim step to determine the individual bubble size range in the layer. Two independent capabilities were utilized which made this approach possible: A high-speed strobe camera, designed to capture images of micron size objects such as plankton, and a computer image analyses system, with software designed to analyze bubbles. Stored threshold criteria eliminated many of the potential errors associated with the manual subjective assignment of in-focus, single bubbles. Images of aggregates, or clouds, of less than 50 micron to about 900 micron size bubbles were interactively processed and analyzed in very short time periods. One day was available for the at-sea data collection. Therefore, this investigation is more properly termed a feasibility study.

CAMERA SYSTEM

A micro-plankton camera was developed by Dr. Harold E. Edgerton, Massachusetts Institute of Technology, to obtain micron-size plankton population and speciation data in the deep ocean. Data collection requirements for this camera included slow ship speeds, i.e. on the order of 1 m/s (2 knots). An upgraded version of this camera is marketed by Benthos, Inc., Falmouth, Ma. The prototype camera system used in this study employs a silhouette camera and a strobe assembly mounted in opposing steel cylindrical casings approximately 0.6 mm (0.24 inch) thick (Figure 1). The system covers a field of view with high resolution and has sufficient depth of field to detect bubbles in a 3-dimensional volume. All problems involving diffraction are solved by using a very close subject to film distance, as well as a small light source size at a relatively large distance from the film. The camera has a standard 55 mm lens and the film used is 35 mm, EK 5302, with an ASA of 2. The camera accomodates up to 30 meters (100 feet) of film on No. 10 spools. The strobe assembly provides a 2 microsecond pulse duration strobe light, EG&G type FX-198 lamp with a 3 mm (1/8") gap, and an optical condensing system which receives the light and images the lamp with a high resolution lens. The result is a silhouette of any object in the field of view.

The distance between the plated glass ports of the camera and strobe sections is 46 mm (1.81 in). This restriction caused some concern with respect to possible flow interference, but this aspect was not investigated. The area of coverage has a diameter of about 1.5 cm (3.75 inches), which corresponds to a frame diameter on the film of 0.3 cm (0.75 inch). The film can be enlarged 10 times, without degradation resulting in an approximate 2.5 times enlargement of the actual size. The prototype camera was not remotely actuated but was activated when the connecting cable between the two sections (camera and strobe) was plugged in. The internal gear mechanism cycles the strobe and film advance approximately every 5 seconds. The camera continually sampled until the film ran out, or, until the cable was disconnected.

For this investigation the camera was encased in an aluminum fairing and the camera assembly was rigidly attached to the air generator strut, fig 2. The camera was located about 0.6 meter (approximately 2 feet) downstream of the strut, at ship speeds of up to 6 m/s (12 knots). A strong back was built into the fairing to insure mechanical integrity of the camera system. The influence of this solid wall, aft of the camera-strobe gap, on water flow lines was not investigated.

COMPUTERIZED BUBBLE IMAGE ANALYSIS SYSTEM

The Bete Fog Nozzle Company, Greenfield, Ma. produces spray nozzles for application in industrial and agricultural research and in pollution control, particularly wet scrubbing and evaporative disposal. As such they are concerned with optimizing the distribution of water spray droplet sizes in air. Quality control considerations required development of an in-house capability to measure and analyze micron size water droplets at high speeds. Custom software was developed by Bete to achieve this objective. A system flow diagram, figure 3 , graphically depicts the data acquisition and processing hardware system. The work reported here was conducted in 1982, and significant changes in the system have been implemented. For the benefit of the reader the updated system only is described as a direct commentary to figure 3 as follows:

SYSTEMS SPECIFICATIONS AND CAPABILITIES

A. Data Acquisition

1. Video Camera - For routine applications a direct image measurement is made, analogous to photography. A Dage Video Camera and Newvicon Tube with interchangeable lens is continuously ready to receive and transmit bubble image frames. Rapid image measurement permits measuring bubble velocities of from 0 to 1000 m/sec (0.2 - 3000 ft/sec), yielding spatial data. The lens system has been changed from a special fixed focal distance lens to a 75 mm C-mount lens. The system is compatible with existing high quality video recording systems. The pixel resolution of the system is 2 microns, μ. Magnification of the camera lens is variable from 1 X to 35 X.

2. Key/CRT - Operator control of the system is simplified by computer output menus and prompting. A DEC VT 100 - Terminal and a Video CRT comprise this module.

3. Strobe Lamp - The light source now uses two EG&G Strobes - externally synchronized to computer control. In the dual strobe mode the system automatically calculates flow velocity, as determined from bubble displacement during two succeeding strobe flashes. The lamp emits a controlled 2 μsec long light pulse when the image processor outputs a signal to the strobe unit.

B. Data Processing

4. Image Processor - The strobed video image is entered by coaxial cable to the input of the image processor which analyzes and digitizes the video picture information and appropriately interacts with the video frame storage.

5. Video Frame Storage - This keyboard controlled component consists of an OCTEK-A/D Converter, frame storage, high speed image analyzer, 320 X 320 X 4 bit per image capacity. The frame data storage capacity is 3,000 - 5,000 frames of approximately 12-20 bubbles per frame. The video frame storage capacity is 50 complete bubble aggregate images, on a Winchester disc, with floppy disc back-up frame storage.

The maximum total process time per frame from strobe pulse to processed data, has been reduced from three seconds to one second.

6. Video Monitor - The display screen measures 10" diagonal and 7" width. Visual magnification of a bubble on the monitor screen is variable from 10 X to 350 X actual bubble size. This interactive component enables the operator to review the data and to make processing decisions. Sixteen gray levels can be set to correlate with focus. The operator can adjust the limits of the focus to determine the depth of field, for volume determinations. A wide total size range of from 2 to 10,000 microns is achievable.

RANGE, MICRONS	OPTICAL MAGNIFICATION	MAGNIFICATION AT THE MONITOR
80 Microns to 10,000 Microns	1.40	10.00
8 Microns to 1,000 Microns	12.50	87.50
6 Microns to 770 Microns	16.25	113.75
4 Microns to 500 Microns	25.00	175.00
2 Microns to 250 Microns	50.00	350.00

The dynamic range of the system is 120 X, i.e., 2-240μ, 20-2400μ, etc..

7. Computer - A DEC based PDP-11/23 is now used with a 256 kbyte RAM storage. The Winchester disc provides a 10 MBYTE storage DOS, an increase of 15 X over the preceding system.

8. Printer - A DEC printer, Model LA 100, produces the hard copy data products. The standard printout includes tabulated frequency of occurrence vs. size range, average diameters etc., see table 1. A graphics capability includes histograms of size distribution spectra, bar graphs, etc., and, high fidelity copies of bubble images, as seen on the monitor.

The image analysis system was specially adapted for this test program to analyze photographs of bubble images, figure 4, rather than in situ imaging, as shown in figure 1. This adaptation procedure was as follows:

a. Set-up: The TV camera was mounted vertically facing down with the camera lens looking through a fluorescent ring light for uniform illumination. A transparent grid overlay, inked lines on mylar forming 15 mm vertical by 19.5 mm horizontal rectangles, was positioned over the photograph for framing purposes, figure 5.

The super-white border feature of the Droplet (bubble) Analyzer was adjusted to match the overlay rectangles for alignment and orderly processing when viewing on the video monitor.

b. Calibration: A thin circular disc of accurately measured diameter was fabricated for calibration purposes; it was sprayed with a blue dye lacquer (Dye Chem) to reduce reflected light. The disc diameter was measured ten times with a freshly calibrated micrometer. The average micrometer reading of 11,136 microns (μ) was used in all subsequent work. The disc diameter was then measured repeatedly with the droplet analyzer. The average analyzer reading was 11,132.8 microns; an error of 0.03%. The spread about the 11,136 value was +0.04% to - 0.11%. The calibrated disc was placed on each calibration photograph, centered on the millimeter scale of six photographic images of a reference reticule. The average of all photographic readings of the reticule was 4,604 microns, and the maximum spread about the average was +0.46% and -0.52%. The photographic magnification was determined:

$$\text{Photographic magnification} = \frac{\text{Disc diameter}, \mu}{\text{Average of Photo Readings}, \mu} = 2.419$$

The system was calibrated to include this magnification factor as follows:

$$\frac{\text{Regular calibration ratio}}{\text{Photographic magnification}} \quad \frac{68.11}{2.419} = 28.156\ \mu/\text{pixel}$$

Thus, all of the bubble size data was presented as true size, and not as a photographically enlarged size.

c. Results: Each data set contains:

1. The original photograph, figure 4
2. Photocopy with overlay and annotated by

   total number of bubbles analyzed ,

   out-of-focus bubbles rejected ,

   in each grid frame location analyzed, figure 5
3. Computer printouts of
   a. 10 frame grabs, system verification on an 11,136 micron disc, analyzed in full size.

   b. 5 frame grabs on an isolated bubble to provide a record of repeatability.

   c. 48 sequential grid (frame) statistics on all frames analyzed.

d. Tabulated statistical summary of the entire image; a composite of all grids, table 1

A plot of the data shown in table 1 is presented in figure 6. The predominant bubble size range determined from the five data sets analyzed is approximately 100-300 microns. As mentioned previously the time required to analyze each grid section was only one minute.

SUMMARY

Existing equipment for underway monitoring of microbubble size distribution in the ocean is relatively scarce. The combined use of two independent resources resulted in successful data acquisition of micron-size bubble aggregates in a dynamic open ocean environment and in an efficient method of analysis of the data. A unique photographic camera-strobe system was successfully used to acquire this data; the microsecond pulse duration of the strobe is one of the critical elements of this system. The computerized image analysis system, with the Bete developed software for bubble data processing and analysis, saved valuable time and provided a high-level of confidence in the data products. The photographic camera system approach represents an interim measure, as the overall objective is to achieve high resolution 3-D monitoring of the characteristics of a bubble aggregate while underway, optical or sonic. The overall goal is to attempt to optimize the bubble size distribution and percent air content with respect to control of acoustic properties. An attempt to monitor size is reported here, but the void ratio or percent air per unit volume measurement was not yet attempted. A successful attempt was made to monitor the volume of an air layer while underway, using a fiber optic detector array, and is reported separately.

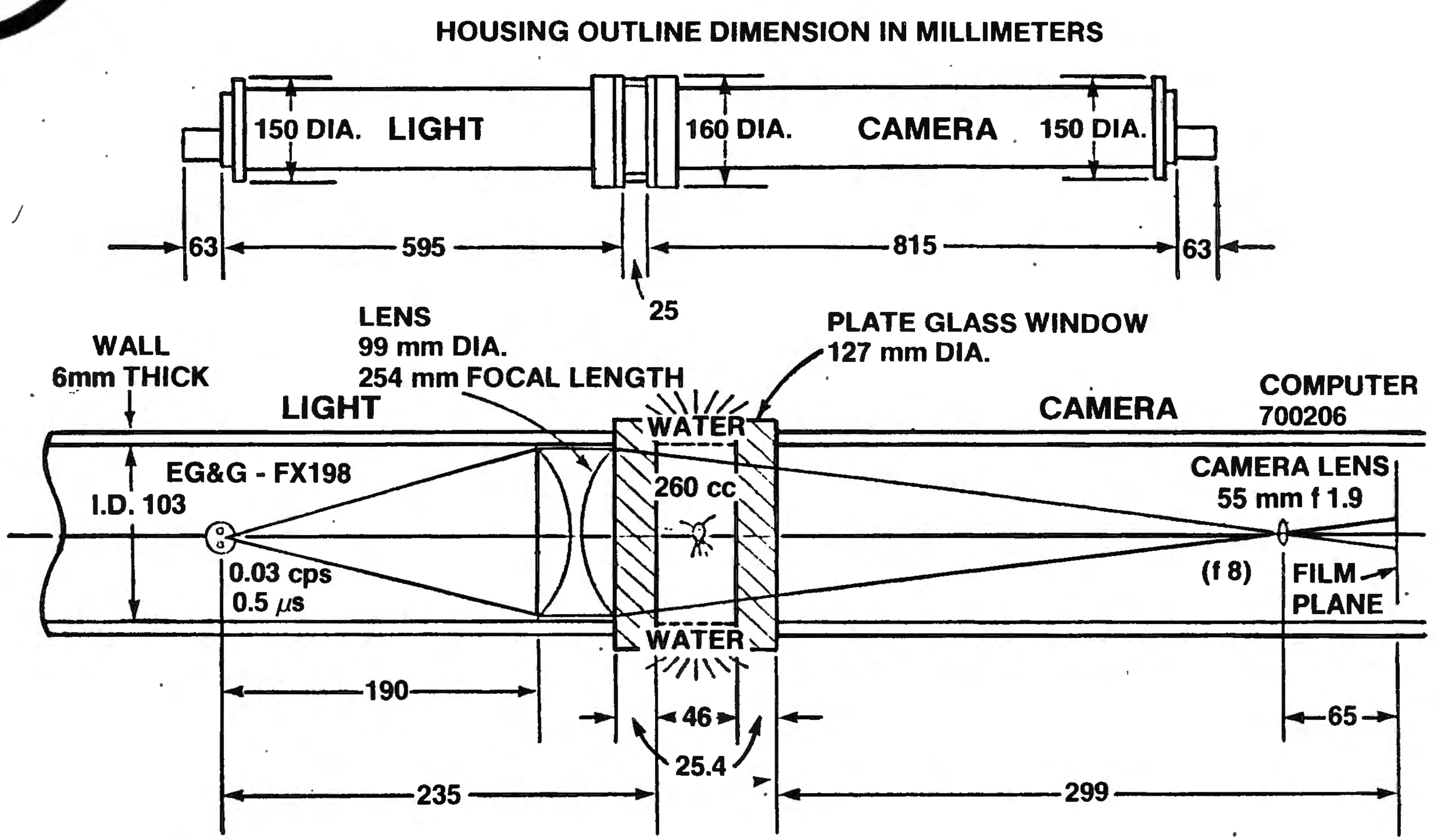
RECOMMENDATIONS

While the subject interim approach was successful, it constitutes a multi-step and overall time consuming process. The photographic film must be developed and assessed and frames selected for analysis. If the data analysis is not performed frequently there is a set-up time required to adapt the image analysis system to the photographs. Since the droplet (bubble) analyses is designed to receive image data directly from a video camera emphasis should be placed on modifying the data acquisition technique. The specifications of the existing video camera, for acquiring water droplet data in air, are similar to the photographic camera used in this study. Preliminary analysis of a feasibility study to use the existing video camera underwater has produced positive results. Data collected from the video system, with microsecond strobe pulse duration, will not only be directly compatable with the image analysis system, but will also provide a real-time shipboard monitoring capability. Currently, there is no known Navy effort to advance this technique.

REFERENCES

1. Holmberg, G., Allard, F., Brown, D., Flately, J., Gallagher, J., Morency, R., and MacMillan, W., "Underwater Bubble Detection Using an Array of Fiber Optic Sensors" OCEANS '84 Conference, Sep, 1984.

M.I.T. CAMERA DIMENSIONS



PLANKTON CAMERA
MIT APRIL 1979 H. EDGERTON
ALL DIMENSIONS IN MILLIMETERS

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FIGURE 1

CAMERA FAIRING (side view)

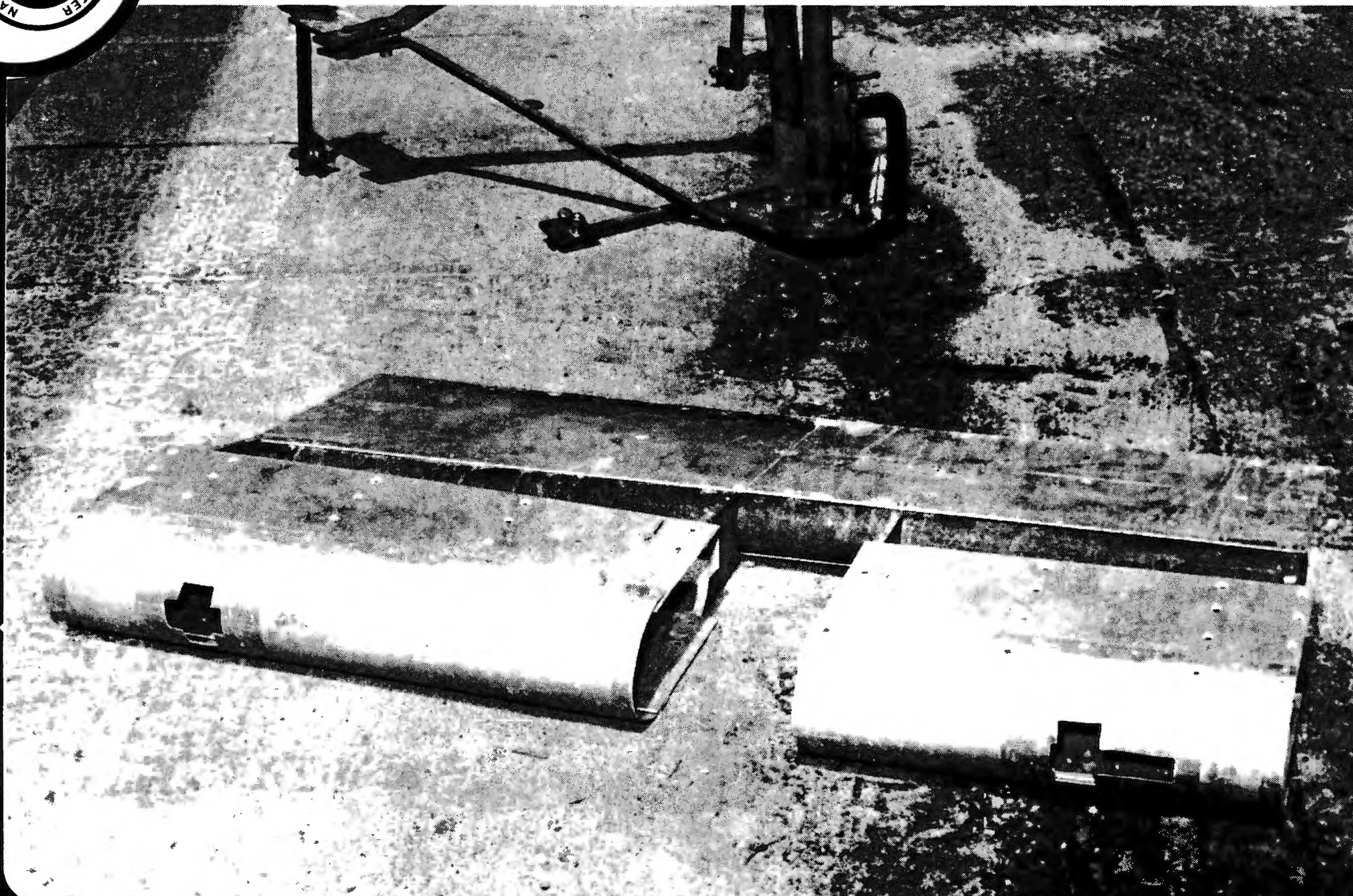

FIGURE 2

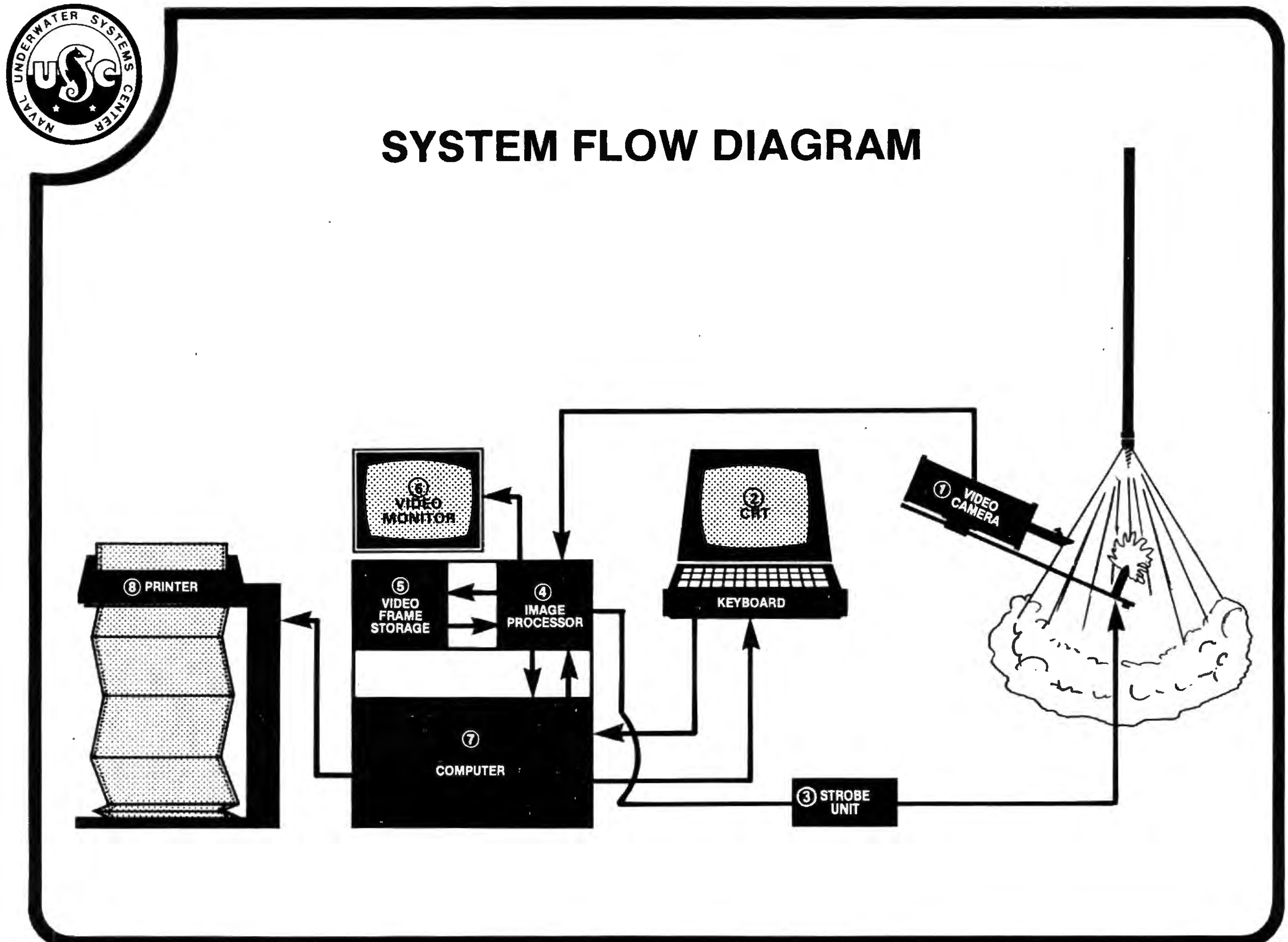
NAVAL UNDERWATER SYSTEMS CENTER
USC
SYSTEM FLOW DIAGRAM
⑥ VIDEO MONITOR
② CRT
① VIDEO CAMERA
⑧ PRINTER
⑤ VIDEO FRAME STORAGE
④ IMAGE PROCESSOR
KEYBOARD
⑦ COMPUTER
③ STROBE UNIT

FIGURE 3

IMAGE OF BUBBLE AGGREGATE

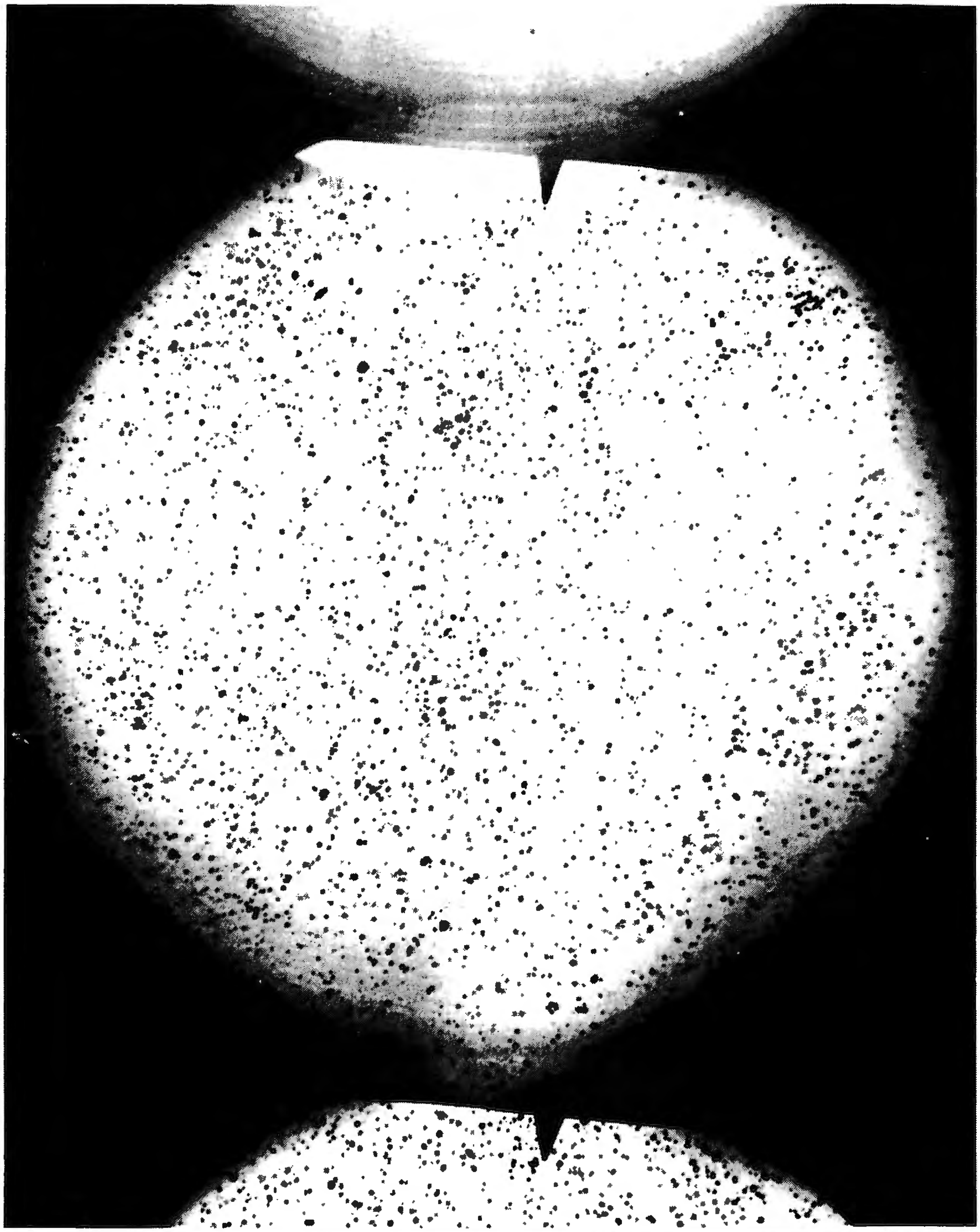

FIGURE 4

ANNOTATED COPY OF BUBBLE PHOTOGRAPH

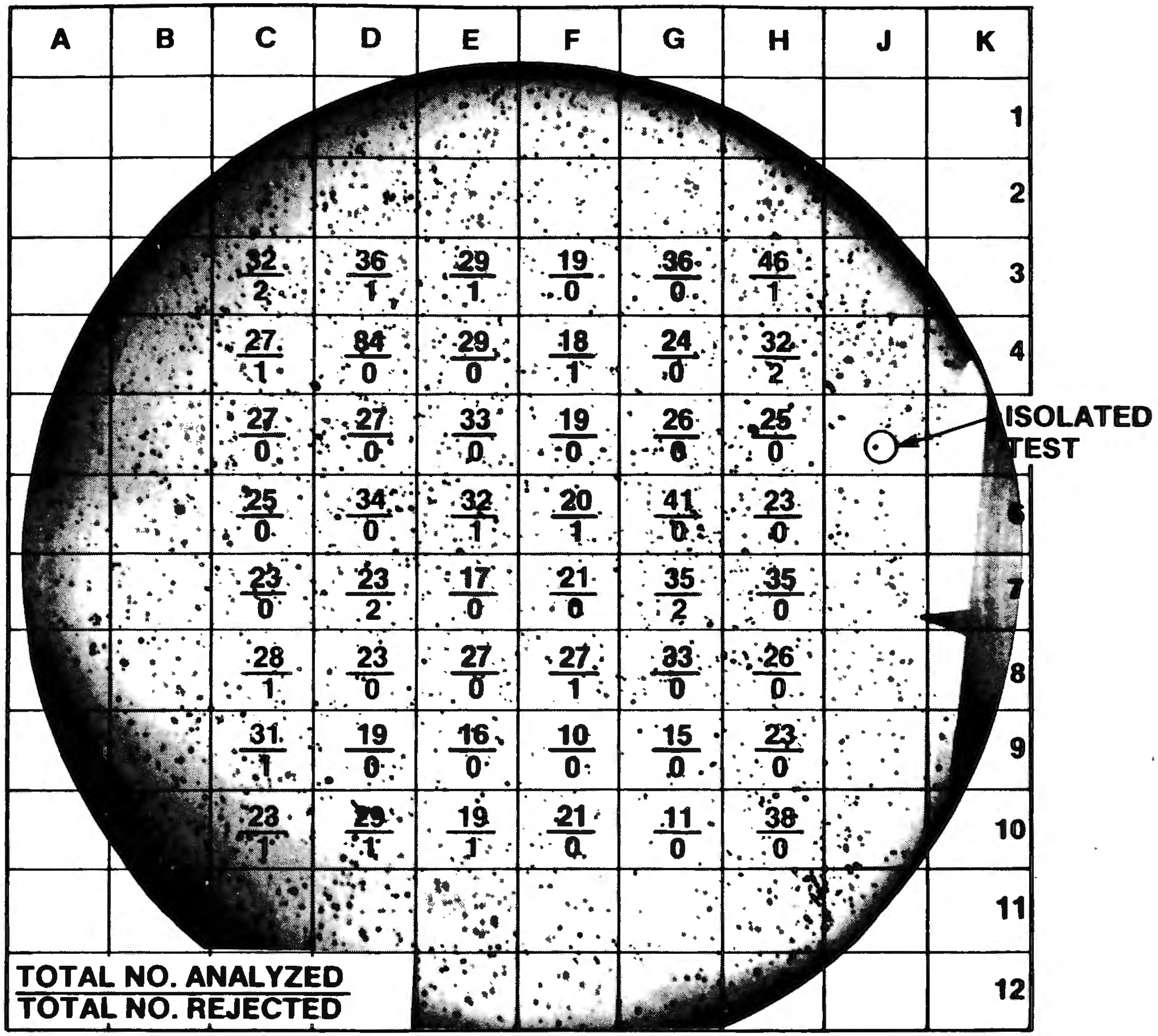

FIGURE 5

TABULATED BUBBLE SIZE STATISTICS

8/26/82 BETE DROPLET ANALYSIS SYSTEM

BOUNDS FOR REPORT:

TEST DATES 8/25/82 - 8/26/82
TEST NUMBERS 1 - 5
0.0 PSI 0 DEG AZ. ANGLE
0 DEG CONICAL ANGLE 0.00 INCHES DIST

DIAMETER (MICRONS)	DROPS	% OCCURRENCE	% SURFACE AREA	% VOLUME	CUM % VOLUME	CLASS CHECK
26.9 - 33.6	605	5.41	0.11	0.01	0.01	0.000
42.0 - 52.5	569	5.09	0.21	0.03	0.04	0.000
52.5 - 65.7	571	5.11	0.34	0.06	0.09	0.000
65.7 - 82.1	439	3.93	0.44	0.10	0.19	0.000
82.1 - 102.6	798	7.14	1.22	0.33	0.52	0.000
102.6 - 128.3	1066	9.54	2.59	0.88	1.40	0.001
128.3 - 160.3	1371	12.27	5.18	2.20	3.61	0.002
160.3 - 200.4	1491	13.34	8.67	4.57	8.18	0.005
200.4 - 250.5	1497	13.40	13.56	8.93	17.11	0.010
250.5 - 313.1	1238	11.08	17.43	14.31	31.42	0.016
313.1 - 391.4	797	7.13	17.58	18.07	49.49	0.020
391.4 - 489.2	455	4.07	15.37	19.55	69.04	0.022
489.2 - 611.5	200	1.79	10.47	16.57	85.60	0.018
611.5 - 764.4	61	0.55	4.83	9.39	94.99	0.010
764.4 - 955.5	15	0.13	1.99	5.03	100.02	0.006
	11173	100.00	99.99	100.02	100.02	

AVERAGE DIAMETERS:

ARITHMETIC MEAN =	187.15	MAXIMUM DIAMETER =	955.54
SURFACE MEAN =	223.12	MINIMUM DIAMETER =	31.76
VOLUME MEAN =	257.49	TOTAL # DROPS IN SAMPLE =	11173
SAUTER MEAN =	342.93	TOTAL # FRAMES IN SAMPLE =	240
WEIGHT MEAN =	419.98	DROPS PER FRAME =	46.55
VOLUME MEDIAN =	394.09	SAMPLE SIZE CHECK =	0.00
		DEVIATION =	0.52

RELATIVE SPAN = (680.86 - 212.94)/394.09 = 1.19

TABLE 1

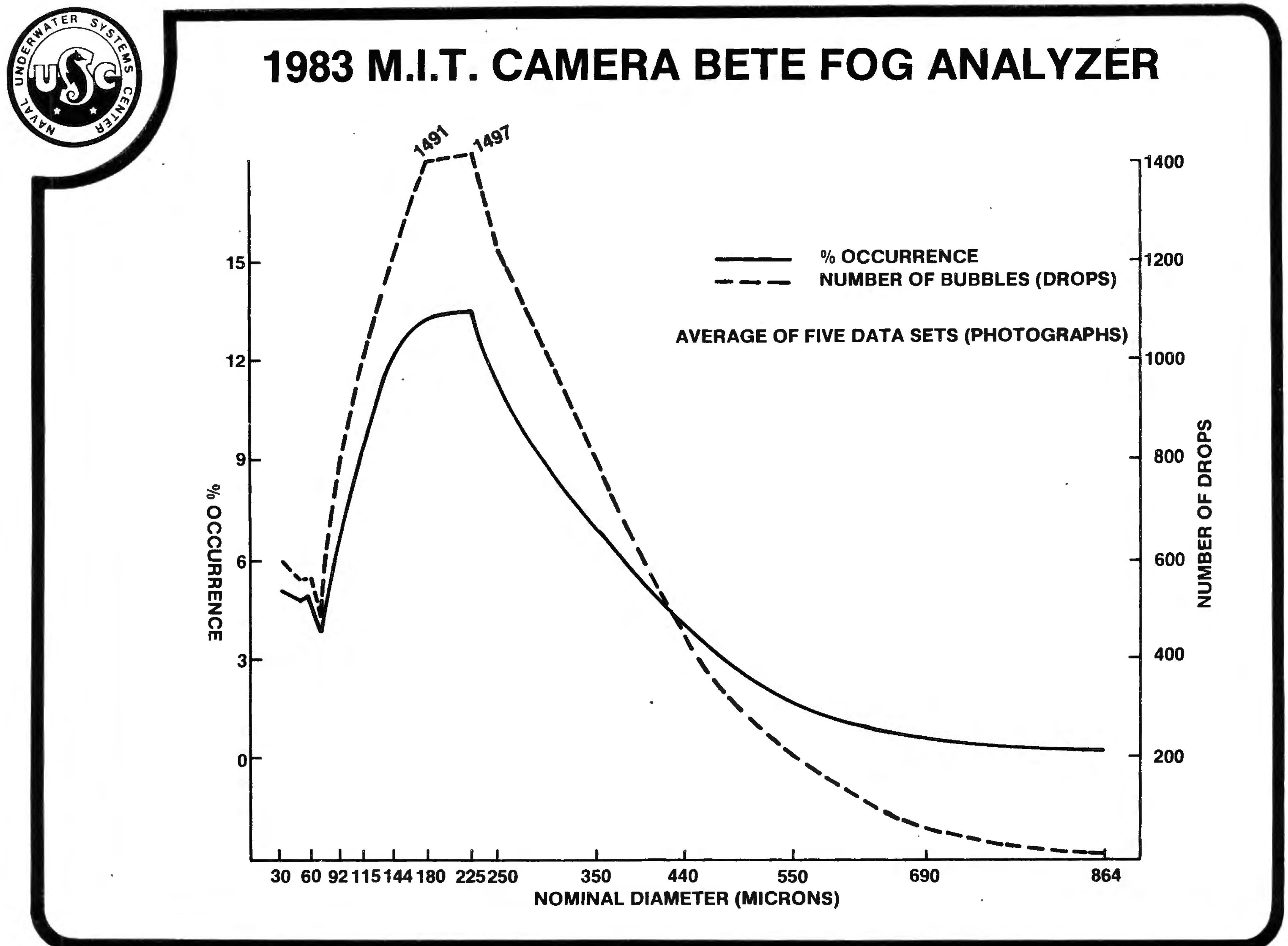
1983 M.I.T. CAMERA BETE FOG ANALYZER
1491
1497
% OCCURRENCE
NUMBER OF BUBBLES (DROPS)
AVERAGE OF FIVE DATA SETS (PHOTOGRAPHS)
15
12
9
6
3
0
% OCCURRENCE
1400
1200
1000
800
600
400
200
NUMBER OF DROPS
30 60 92 115 144 180 225 250 350 440 550 690 864
NOMINAL DIAMETER (MICRONS)

FIGURE 6

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